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(54) Title: FIBRE OPTIC DEVICES

(57) Abstract

A fibre optic device which can be used as an attenuator or a sensor. The fiber has a biconical taper which can be immersed in a medium having a higher refractive index so that light transmission through the fibre can be used as a sensor in measuring temperature, refractive index. When used as a tuneable attenuator electrodes are mounted in contact with the medium so that it can be heated to vary transmissivity through the fibre.

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Fibre Optic Devices

The present invention concerns optical fibre devices. It has been discovered that optical fibre couplers can be fabricated by imparting a biconical taper to a monomode optical fibre. With the aid of such tapering the core HE_{11} mode can couple into the HE_{11} mode of the tube waveguide, which is formed due to the cladding, in an efficient manner.

The present invention has for an object to utilise optical fibres having such biconical tapers to form devices, including sensing devices and tuneable attenuators, which are simple to manufacture and which incorporate low cost electronics.

Accordingly from one aspect the present invention consists in an optical fibre device comprising a monomode optical fibre having an optical coupler fabricated therein in the form of a biconical tapered portion, means for modifying the refractive index of a medium surrounding the tapered portion so that for a specified wavelength travelling along the fibre the power transmitted will vary in accordance with variation in the refractive index of the medium, and means for detecting light transmitted by the core of the optical fibre.

In order that the present invention may be more readily understood, two embodiments of devices constructed in accordance with the invention will now be described

by way of example and with reference to the accompanying drawings, in which:

Figure 1 shows various refractive index profiles taken across the diameter of optical fibres suitable for use in sensors according to the present invention,

Figure 2 is a plot of transmitted power against extension of an optical fibre during the process of producing a biconical taper in the fibre,

Figure 3 is a plot similar to Figure 2 showing the effect of stopping extension at a selected point,

Figure 4 is a plot showing the refractive index response of the taper, the refractive index varying in response to temperature variations,

Figure 5 is a diagram showing how a temperature-linked refractive index variation can be applied to a tapered fibre to make a fuseable attenuator,

Figure 6 is a plot of the refractive index response of a tapered fibre at a second wavelength,

Figure 7 is a diagram of a sensing device, and

Figures 8 to 10 are vaious plots again showing the responses obtained to varying degrees of taper and surrounding refractive indices.

Referring now to the drawings, the refractive index profiles shown in Figure 1 show some of the types of single mode optical fibres which can be utilised in carrying out the present invention. The profiles a, b, c, d, e and f respectively relate to Matched, Depressed, Quadruple Clad, Segmented Core and Raised Cladding optical fibres.

All these types of fibre can be formed into coaxial couplers by the process described in our co-pending U.K. Application No. 8519086 entitled "Coaxial Couplers". In this process laser light is launched into one end of an optical fibre and the transmitted power detected at the other end. Whilst the light is being transmitted a portion of the fibre is simultaneously heated and elongated, generating a biconical taper in the fibre. The light guided in the core of the single mode fibre is directed

into the tapered section. The tapering being applied causes the tapered portion to become a multi-mode section, and interference of the local HE_{11} and HE_{12} modes causes power transfer along the taper. If the taper length is such that for the particular taper shape power emerges at the taper end in the core of the fibre, then the light will be transmitted. If, however, it emerges in the cladding it will be lost. This can be seen from the plot shown in Figure 2 which consists of power oscillations induced by the tapering process. Figure 2 shows the result if the taper is elongated until it breaks. However, the tapering process can be stopped at will. Figure 3 shows the power transmission response when extension of a fibre portion to produce a biconical taper has been stopped just after 1½ detected power oscillations.

A tapered optical coupler produced by this procedure can be incorporated in a range of sensing devices by utilising the refractive index response of the tapers. Then if the tapered portion is immersed in a liquid such as silicone oil, which has a higher refractive index than silica, and the liquid is heated so that its refractive index varies the response of the taper to light of a particular wavelength will vary. This variation is shown in the plot of Figure 4.

From this plot it can be seen that there is maximum power transmission at point A. This is at a temperature of 29°C. At higher temperatures the power throughput decreases almost linearly as temperature rises. Thus point B shows power transmission at 55°C. The section A-B of the plot can be used to provide a sensor with relatively low sensitivity and good dynamic range in which a change of refractive index of the order of 10^{-2} corresponds to a change in temperature of approximately 30°C, and requiring a detection sensitivity range of ~20 dB. These figures provide the basis for an intensity sensor for the measurement of temperature, refractive index, acoustic, biological and other sensors

which directly or indirectly use this refractive index and intensity relation.

However use of such a device as an intensity sensor raises a number of problems. For example, external variations such as bending, microbending, etc. could affect the intensity transmitted. To overcome these drawbacks some form of compensation is required. This can be achieved by a dual wavelength transmission. Figure 6 is a plot of the refractive index response of the same taper at a second wavelength when subjected to the same changes in refractive index as caused the plot of Figure 4. It will be seen here that the linear slope A-B of Figure 4 has been replaced by a substantially constant plateau. It is the ability of a single fibre to give two such separate results which enables a compensating factor to be built in to a sensor.

Such a compensated sensor is shown in Figure 7. Laser light at two differing wavelengths λ_1, λ_2 is launched down a single monomode optical fibre 10 which has a biconical taper imparted to it at 11 and which is surrounded by a sensor area generally indicated at 12. This sensor area could, for example, be a capillary tube filled with silicone oil as in the embodiment shown in Figure 5. In any case it will be such that the tapered portion 11 will give power transmission plots of the kind shown in Figures 4 and 6 in response to changes in the refractive index of the surrounding sensor area, and in response to light of wavelengths λ_1 and λ_2 respectively. The two wavelengths can be launched into the fibre by means of a coupler. It will be appreciated that with a device of the characteristics just described measurement will only occur at wavelength λ_1. At the output end of fibre 10 the two wavelengths λ_1 and λ_2 are separated, for example, by another coupler and the power transmitted by each of the wavelengths detected by detectors D1 and D2.

The outputs of the detectors are connected to logarithmic amplifiers 16, 17 the outputs of which are divided by a divider 18. The result is a linear output as a function of temperature, or of refractive index of the substance surrounding the biconical taper. Thus temperature, refractive index and acoustic sensors can be made with this arrangement.

Such sensors would be simple to make with low cost electronics.

Another application involving this relationship, and in particular part A-B of the refractive index response is that of a tuneable attenuator. By changing the refractive index surrounding the taper the throughput attenuation is changed linearly in dB. Thus Figure 5 shows a tuneable attenuator. A monomode optical fibre 1 has a biconical taper fabricated in it in the region generally indicated at 2. This region is housed in a capillary glass tube 3 filled with a liquid such as silicone oil the refractive index of which varies with temperature over the required ranges. The ends of capillary 3 are sealed with UV-cured epoxy resin. The tube is coated with resistive material and provided with electrodes 4 and 5. The application of a voltage across the electrodes causes the heat released to heat the liquid and lower its refractive index, hence varying the transmission through the fibre 1. In this manner a tuneability of >30 dB can be achieved.

Referring again to the plot of Figure 4, it can be seen that there is maximum power transmission at point A. Thus an optical modulator can be constructed using this fact. To manufacture an optical modulator a monomode fibre is surrounded with a material having a refractive index which has a value selected to provide maximum power transmission. By shifting refractive index of the surrounding material higher (to the left of Figure 4) the transmission power is rapidly reduced to a minimum, a loss of approximately 30 dB.

Variations are possible on this basic concept. Figure 4 shows a plot which has been derived using a tapered biconical fibre the elongation of which has been stopped after 1½ power oscillations. If instead the fabrications of the taper had been extended to two complete power oscillations, as shown in Figure 8, then using this biconiclly tapered fibre to produce a plot in response to changes of refractive index results in the plot of Figure 9. Similarly extending the number of oscillations to 12 produces the equivalent plots of Figures 7 and 8.

One advantage afforded by the effect of the increased taper as illustrated in Figures 8 and 9 is that the range of shift required in the refractive index to produce modulation is narrower. This is even more apparent when examining the plots of Figures 10 and 11 where the effective bandwidth of changes in the refractive index along the central peak (between power points -45 and -38.3 dB) is very small. Here also the refractive index can be varied in either direction to obtain modulation. This latter arrangement does have a potential disadvantage in that very accurate control of temperature may be required.

Whatever the nature of the tapering various types of material can be used for the variable refractive index surrounding medium. One possibility is to use an electro-optic material having a sufficiently low refractive index tp match SiO_2 fibres. Alternatively the monomode fibre could be fabricated from a material having a high enough refractive index to match an electro-optic crystal such as KDP. The electro-optic effect could then be used so that the tapered fibre portion and the crystal together act as a modulator. If an electro-optic crystal is used as a cladding medium surrounding the taper it must be grown carefully around the taper. It is possible to

grow single KDP crystals long enough to clad the taper region and also to enclose the modulating electrodes.

As an alternative, low refractive index liquid crystals are used with SiO_2 guides or with high refractive index glass fibre tapers.

For modulators of the kind just described the necessary change of refractive index of the surrounding medium is $< 10^{-3}$.

Such a modulator would find ready application in digital transmission systems. The actual structure of a modulator employing the principles just discussed is similar to that shown in Figure 5 of the drawings.

CLAIMS

1. An optical fibre device comprising a monomode optical fibre having an optical coupler fabricated therein in the form of a biconical tapered portion, a medium surrounding the biconical tapered portion of the fibre, the refractive index of the medium being capable of variation whereby for a specified wavelength travelling along the fibre the power transmitted will vary in accordance with variations of the refractive index of the medium, and means for detecting light transmitted by the core of the fibre.

2. A device as claimed in Claim 1, and including means for launching light at two different wavelengths into said fibre, means for separating the two wavelengths at the output end of the fibre, means for detecting the respective powers of the transmitted wavelengths, and means for generating a compensation factor for one of the wavelengths from the two detected outputs.

3. A device as claimed in Claim 1 or Claim 2, and including means for varying the refractive index of the medium.

4. A device as claimed in Claim 3, wherein the medium surrounding the fibre is chosen so that at a specified condition the fibre offers maximum power transmission to a selected wavelength, and wherein the means for altering the refractive index of the medium do so in such a manner that transmission power is substantially reduced whereby the device can function as a modulator.

5. A device as claimed in any one of the preceding claims wherein the medium is a liquid surrounding the tapered portion.

6. A device as claimed in Claim 5 wherein the liquid is silicone oil.

7. A device as claimed in Claim 6 wherein the means for varying the refractive inded of the silicone oil comprise heating means.

Fig.1.

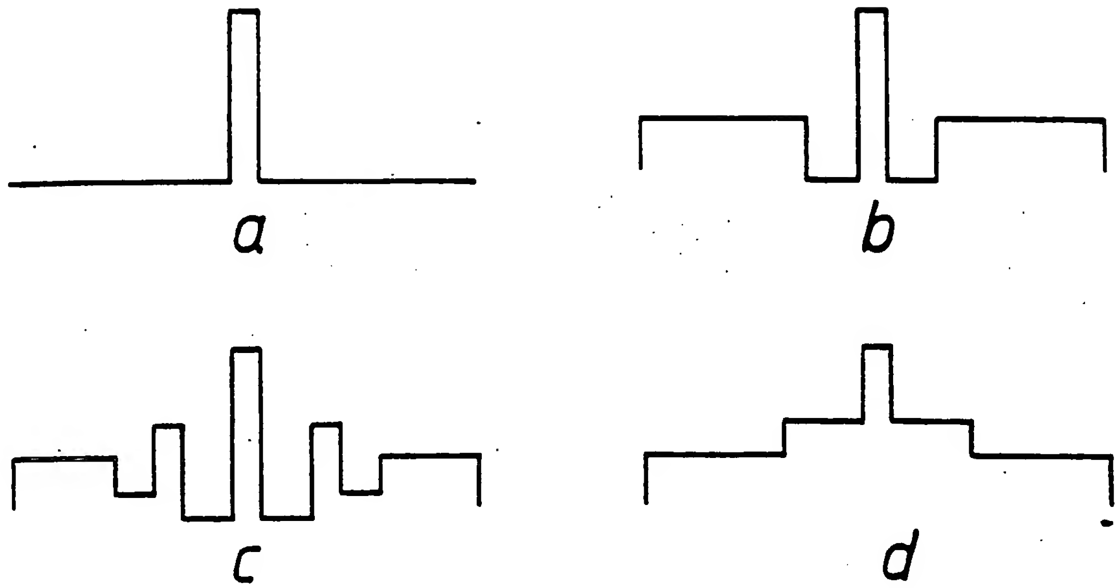


Fig.3.

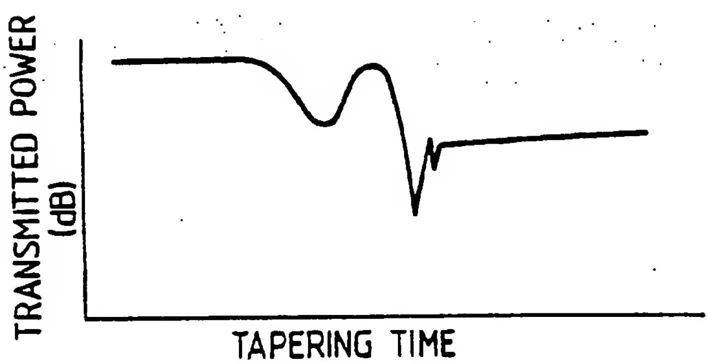
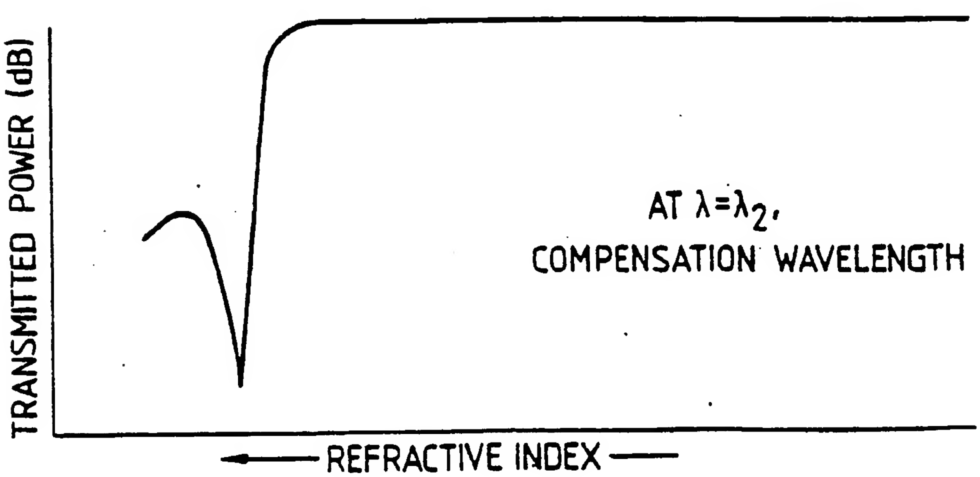


Fig.6.



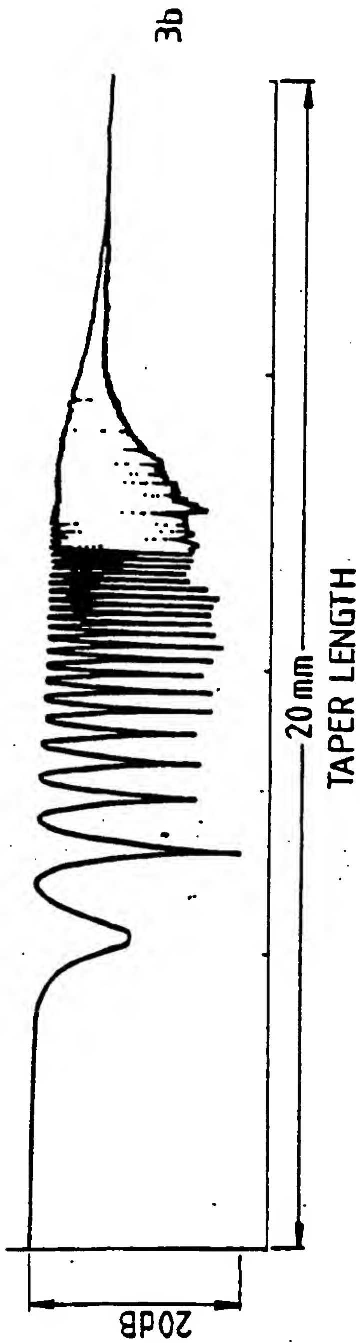

3b
20 mm
TAPER LENGTH
20dB

Fig. 2.

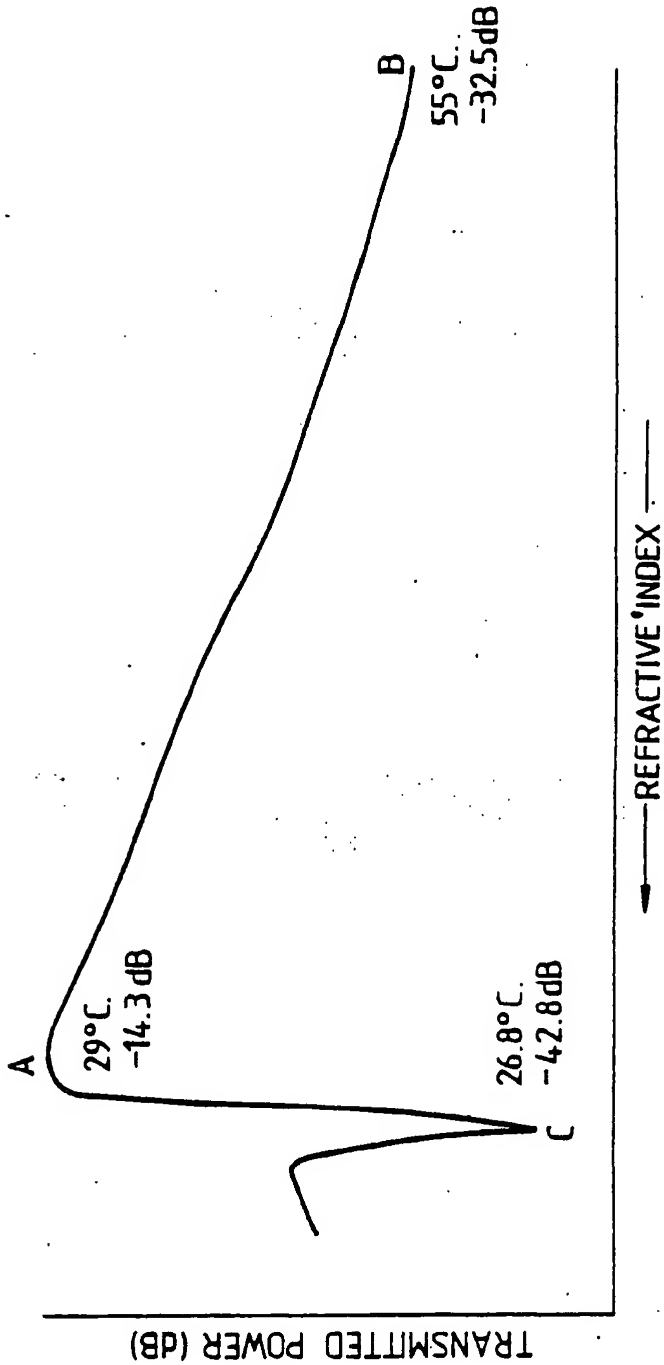

A
29°C.
-14.3 dB
B
55°C.
-32.5dB
C
26.8°C.
-42.8dB
REFRACTIVE INDEX
TRANSMITTED POWER (dB)

Fig. 4.

Fig.5.

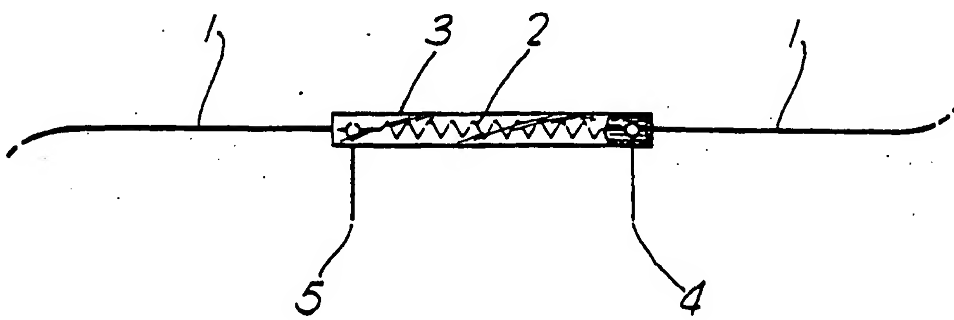
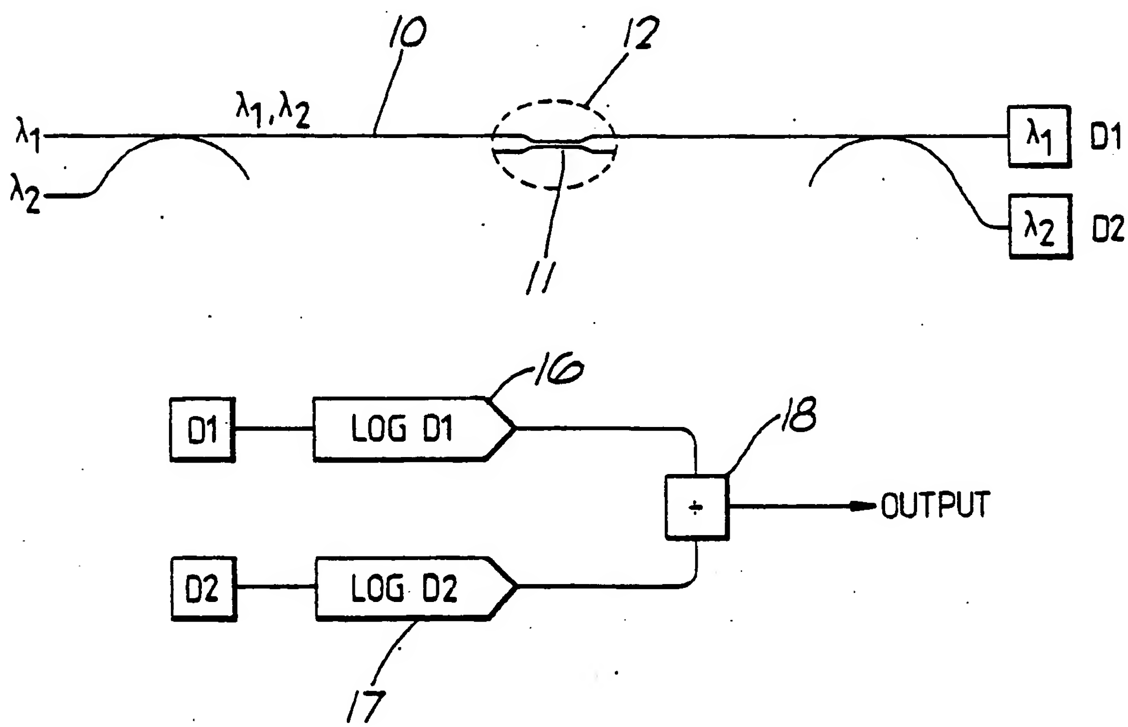

1
3
2
1
5
4

Fig.7.


10
12
λ1,λ2
λ1
λ2
λ1
D1
λ2
D2
11
16
D1
LOG D1
18
÷
OUTPUT
D2
LOG D2
17

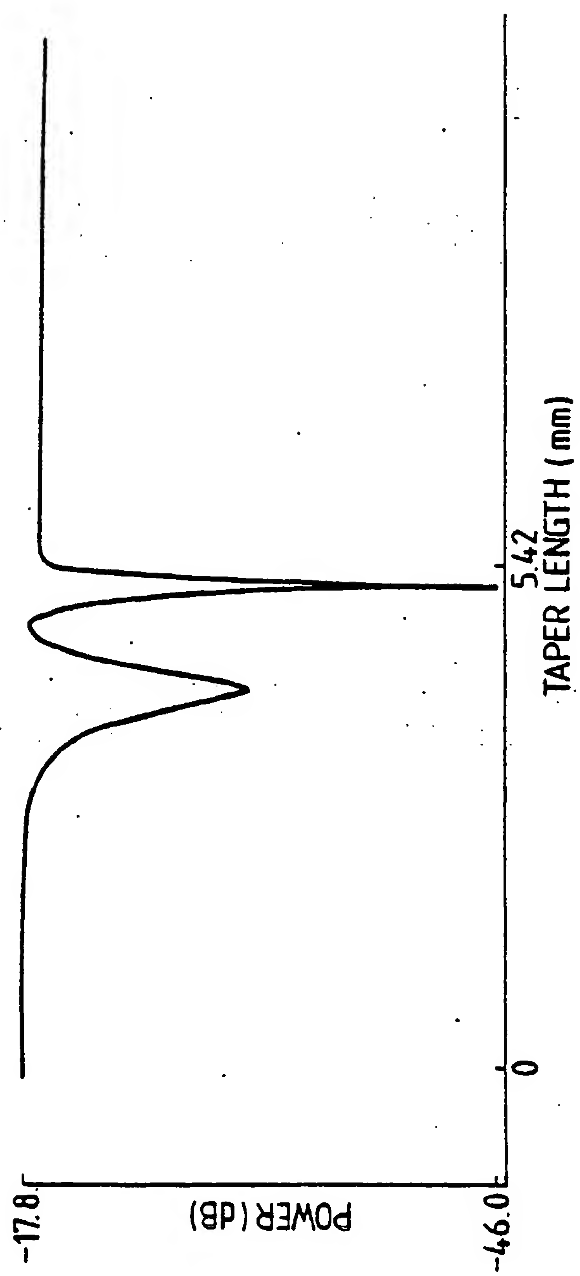

-17.8
POWER (dB)
-46.0
0
5.42
TAPER LENGTH (mm)

Fig. 8.

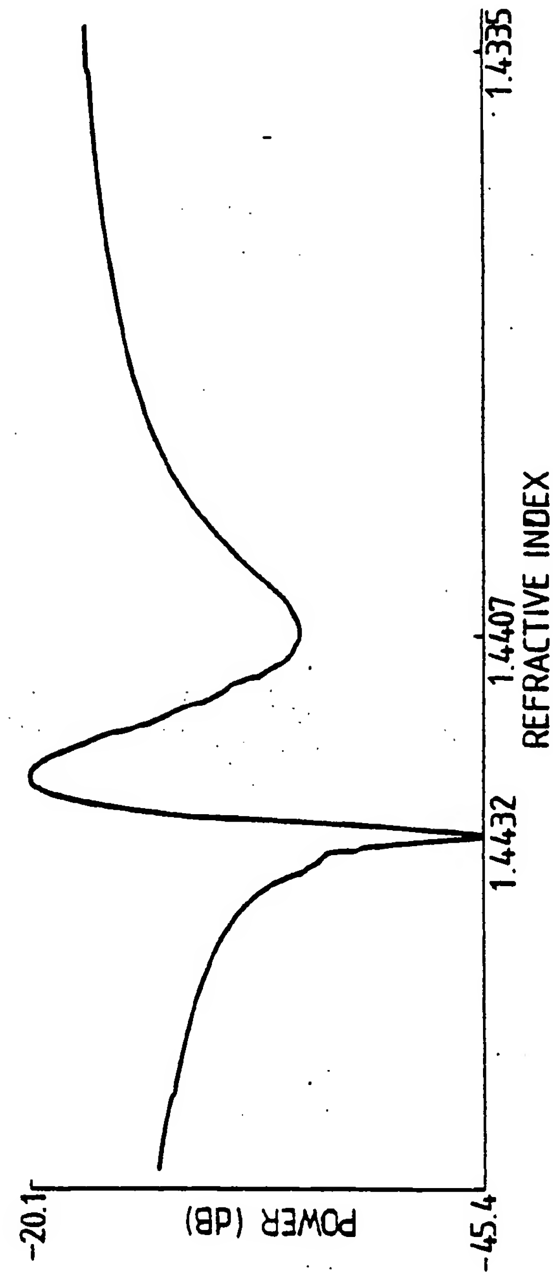

-20.1
POWER (dB)
-45.4
1.4432
1.4407
1.4335
REFRACTIVE INDEX

Fig. 9.

Fig. 10.

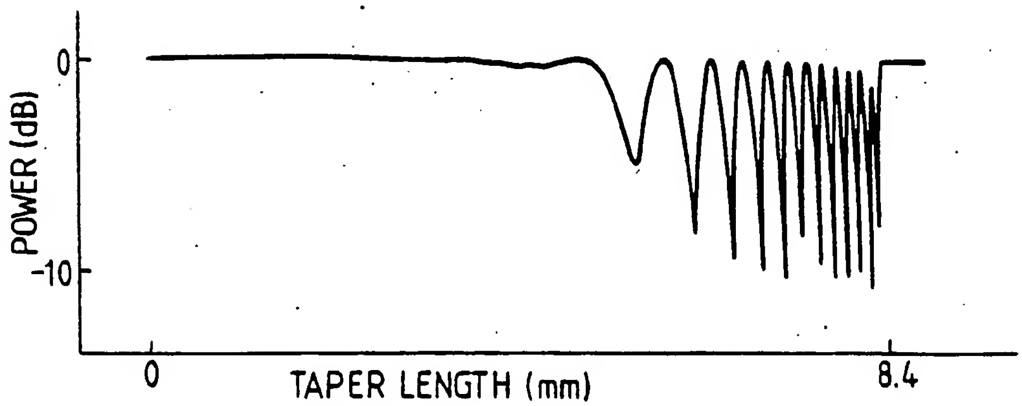
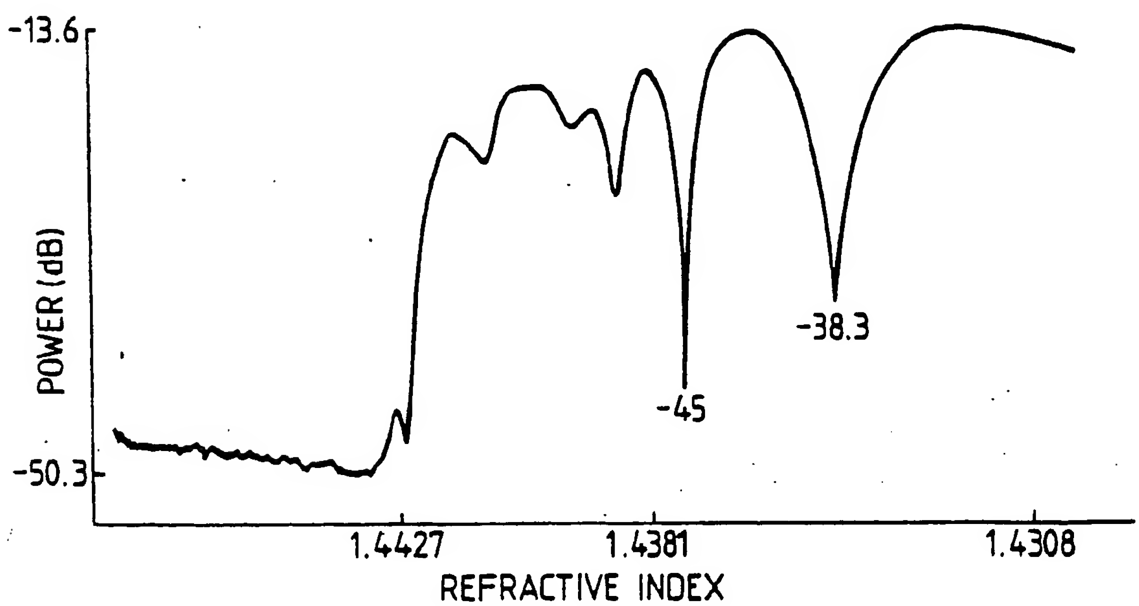

0
-10
POWER (dB)
0
TAPER LENGTH (mm)
8.4

Fig. 11.


-13.6
-50.3
POWER (dB)
-45
-38.3
1.4427
1.4381
1.4308
REFRACTIVE INDEX

INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 86/00738

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC^4: G 01 D 5/26; G 02 F 1/01; G 02 B 6/26

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
IPC^4	G 01 D 5/26; G 02 F 1/01; G 02 B 6/00

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category [*]	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
Y	Electronics Letters, volume 18, no. 15, 22 July 1982, Institution of Electrical Engineers, (Hitchin, Herts, GB), J.R. Cozens et al.: "Optical coupling in coaxial fibers", pages 679-681, see figure 3; page 679, lines 1-17; page 680, lines 29-45, 59-62 --	1,4,5,6
Y	Electronics Letters, volume 21, no. 19, 12 September 1985, Institution of Electrical Engineers, (Hitchin, Herts, GB), A.C. Boucouvalas et al.: "Biconical taper coaxial optical fiber coupler", pages 864-865, see figure 3; page 864, lines 6-20 --	1
A	Applied Physics Letters, volume 42, no. 4, February 1983, American Institute of Physics, (New York, US), V.I. Busurin et al.: "Switchable coaxial optical coupler using a liquid crystal mixture", pages 322-324, see figure 2; page 322, lines 9-49 ./.	1,3,4,5,6,7

* Special categories of cited documents: [10]

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IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
5th March 1987	- 3 APR 1987
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	M. VAN MOL

Form PCT/ISA/210 (second sheet) (January 1985)

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)

Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
A	Journal of Physics E Scientific Instruments, no. 12, December 1984, The Institute of Physics, (London, GB), B.E. Jones et al.: "Optical fiber sensors using wavelength modulation and simplified spectral analysis", pages 1240-1241, see figure 1; page 1240, column 2, lines 1-18	1,2
	--	
A	Electronics Letters, volume 18, no. 3, 4 February 1982, Institution of Electrical Engineers, (Hitchin, Herts, GB), J.R. Cozens et al.: "Coaxial optical coupler", pages 138-140, see the whole document	1,4
